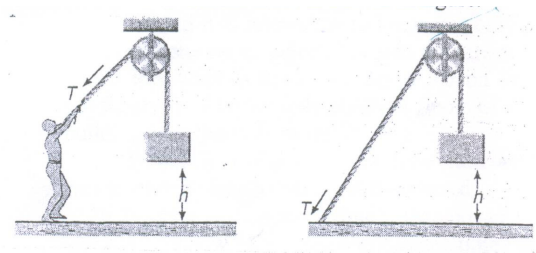
2.4 WORK-POWER-ENERGY

Work:

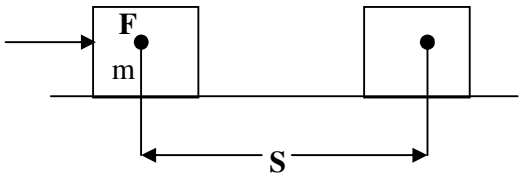
In our daily life work have many different meanings.

Ex: Consider a person holding a weight at a distance 'h' off the floor as shown in figure.



In every day usage, we might say that the man is doing a work, but in our scientific definition, no work is done by force acting on a stationary object. We could eliminate the effort of holding the weight by merely tying the string to some object and the weight could be supported with no help from us.

. In our daily life, the term work refers to any kind of mental and physical activity. For example, Vinod is working in a factory. The machine is in working order, a Professor giving lecture in class and a police man regulating traffic are said to be doing work. But in scientific language, work has a different and definite meaning.



To understand the meaning of work, consider an example of pushing a body of mass 'm' on a frictionless horizontal surface with a certain force through a certain distance as shown in figure. Clearly we are doing a certain amount of work.

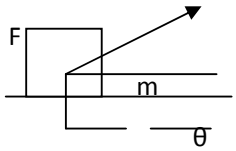
The amount of work is more if we push the body with a greater force through the same distance or with the same force through a longer distance. Thus it is clear that for work to be done two conditions must be fulfilled.

(a) a force must be exerted and
(b) the exerted force must produce motion or displacement.

Thus **work is said to be done by a force when it moves a body through a certain distance in the direction of the force** and is measured by the product of the force and the distance through which the body has moved in the direction of the force,

i.e. work done 'w' = force x displacement

$$W = F.S$$



When the force F makes

an angle θ with the displacement 's' then the component of the force F along the displacement 's' is effective in doing the work, i.e. the component of the force along the direction of the displacement Fcosθ is doing work.

Thus the expression for work done by the force F is displacing the body by s can be expressed as

$$W = (F\cos\theta)\, S$$
$$W = FS\cos\theta$$

If $\theta = 0^0$, $\cos\theta = 1$

$$\vec{W} = \vec{F}.\vec{S}$$ i.e, work done is positive

i.e. work is a dot product of two vector.

Hence it is a scalar quantity.

If $\theta = 180^0$, $\cos 180^0 = -1$

W = - F.S, i.e, work done is negative (Work done by frictional force is negative)

If $\theta = 90^0$, $\cos 90^0 = 0$

W = 0, i.e. work done is zero.

Example: A man carrying a suitcase on his head and walking on the road, he is not doing any work because the force he is exerting on the suitcase is perpendicular to the direction of his motion, i.e, $\theta = 90^0$. Hence work done on the suitcase while carrying it is zero.

SI unit of work is **joule (J)**

W =F.S, i.e. 1J = 1N.1m

Work done is said to be 1 joule, if a force of 1 N acting on a body displaces it through 1 m in the direction of force.

1 J = 1 N x 1 m

Power:

Often it is interesting to know not only the work done on an object, but also the rate at which this work is done. We say a person is physically fit if he not only climbs 4 floors of a building but climbs them fast.

Power is defined as the time rate at which work is done or energy is transferred.

If W is the work done in time 't' then power

P = W / t, i.e. Work done / time

P = W / t

The work done by a constant force is

W = F.S

Therefore P = F.S / t, because $\frac{s}{t} = v$

P = F.V

$$\vec{P} = \vec{F}.\vec{V} = F\,V\cos\theta,$$

where 'v' is the velocity.

Thus instantaneous power is given by the product of force and velocity.

Power is a scalar quantity and its SI unit is watt (W)

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ sec}}$$

Power of an agent is said to be 1 watt if one joule of work is done in one second.

Note: Commercial unit of power is HP. 1 HP = 746 watt.

Energy:
Capacity of a body to do work is called its energy. There are many types of energy, e.g. kinetic, potential, electrostatic, magnetic, geothermal, elastic, solar, etc. In this chapter, we will discuss only mechanical energy. Mechanical energy consists of kinetic energy and potential energy

$$ME = KE + PE$$

Kinetic Energy:
Kinetic energy is the capacity of a body to do work by virtue of its motion. The faster the object moves, the greater is the kinetic energy. When the object is stationary, its kinetic energy is zero. An object of mass 'm' moving in a reference frame with velocity 'v' (well below the velocity of light) is said to have kinetic energy given by

$$\mathbf{KE = \tfrac{1}{2} mv^2}$$

$$[\tfrac{1}{2} mv^2 = \tfrac{1}{2} m (|v|)^2]$$

Hence, $\mathbf{KE = \tfrac{1}{2} mv^2}$

a) Units and dimensions of energy are the same as those of work.
b) Some practical units of energy and their relation with SI unit of energy (joule) are
   i) 1 calorie = 4.2 J
   ii) 1 kilowatt hour (kWh) = 3.6×10^6 J

Potential Energy:
Potential energy (PE) of a body is the energy stored in the body by virtue of its position of configuration in a field.
The concept of PE exists only for conservative forces, like gravitational forces, electrical forces, magnetic forces, etc. We cannot define potential energy corresponding to non-conservative forces like frictional forces.
For example, water at the top of a fall, a compressed spring or a stretched elastic band has potential energy.

Mechanical Energy and its Conservation:
The mechanical energy E of a system is the sum of its kinetic energy K and its potential energy U.

$$E = K + U$$

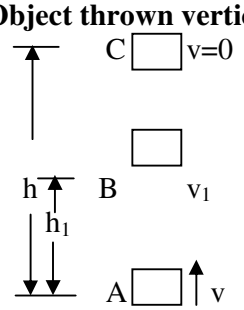
When the forces acting on the system are conservative in nature, the mechanical energy of the system remains constant.

$$K + U = \text{constant}$$

$$\Rightarrow \Delta K + \Delta U = 0$$

There are physical situations where one of more conservative forces act on the system but the net work done by them is zero, then too the mechanical energy of the system remains constant. If $\sum W_{net} = 0$
Mechanical energy E = constant.
Examples of Conservation of Mechanical Energy:

14. Object thrown vertically upwards:

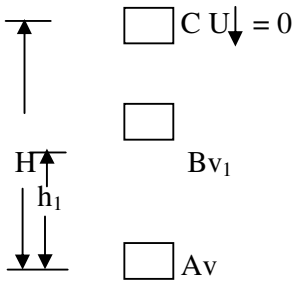


Energy at the lowest point (at A) is only kinetic energy h=0 in the middle, energy is both kinetic and potential energy (as $h=h_1$) and at the highest point, energy is only potential (as v=0)

$$E = K_A = K_B + U_B = U_C$$

Or $E = \tfrac{1}{2} mv^2 = \tfrac{1}{2} mv_1^2 + mgh_1 =$

15. Freely falling object :



$E = U_C = K_B + U_B = K_A$

Or $E = mgh = ½ mv_1^2 + mgh_1 = ½ mv^2$

where, K_A = kinetic energy at A, K_B = kinetic energy at B,
U_B = potential energy at B, U_C = potential energy at C

2.4Questions:

1. What is the amount of work done by centripetal force when the body moves in a circular path?
2. Give relation between momentum and kinetic energy.
3. What does area under force-displacement curve represent?
4. Does kinetic energy of a body be negative?
5. Can a body have energy without having momentum? Explain.
6. How many watts make one HP?
7. When is work done (a) maximum?
   (b) minimum?
8. Is power a scalar or a vector?
9. Does the sun do any work on earth, when earth revolves around the sun in a perfectly circular orbit?
10. Does kinetic energy depends on the direction of motion involved?
11. What physical quantity is determined by area enclosed by force –displacement curve and displacement axis ?
12. Express the kinetic energy in terms of momentum p .
13. When a conservative force does positive work on a body , what happens to the potential energy of the body ?
14. A force of 50 N acting on a body displaces it through 10m at an angle of 300 calculate the work done by the force.
15. If the momentum of the body is increased by 50% its kinetic energy increased by

Answers

2.4 Work power and energy

1. Zero because centripetal force is perpendicular to the displacement.
2. K E = p^2 /2m where p= momentum.
3. Area under force –displacement graph measures workdone by the force.
4. No
5. Yes potential energy at the highest point.
6. 1HP = 746 watts.
7. W = F.S cosθ . θ =0 cosθ =1 W = F S max
   θ =90^0 cosθ =0 W=0 min
8. Power is a scalar quantity .
9. No. because the centripetal force acting on the earth is perpendicular to its displacement .
10. No It is independent of direction of motion.
11. Work
12. KE = p^2 /2m where p= momentum
13. When conservative force does positive work, its kinetic energy increase but potential energy decrease .
14. 250 3 .
15. 125% .